Hydrodynamics Experiments on the NIF: Scientific Accomplishments and Opportunities

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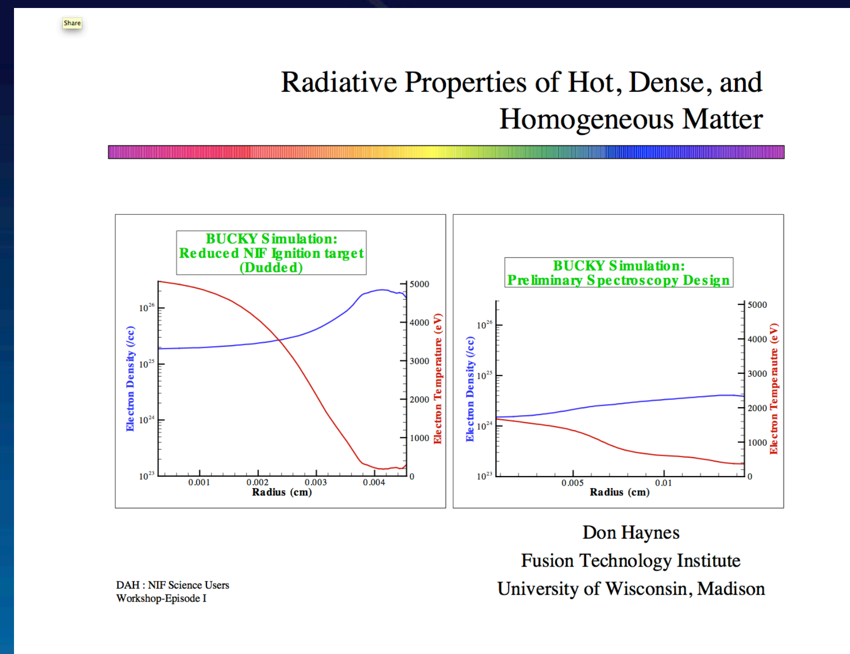
LA-UR-14-20576

It’s been far too long.

- Back in 1999, at what may have been the first NIF Science Users Group Meeting, I discussed the difficulty of using the point design as a platform for line broadening studies (then the most important subject in the universe) and proposed an alternative design.
- Since then I’ve worked on IFE and on weapons.
- I am delighted to be back.



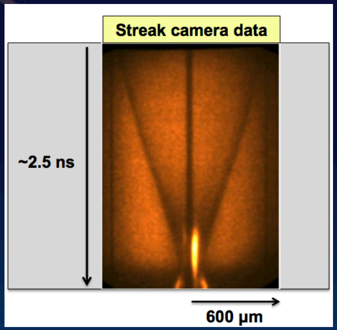
Presented at the National Ignition Facility Science Users Workshop, Pleasanton, CA, 5 October 1999

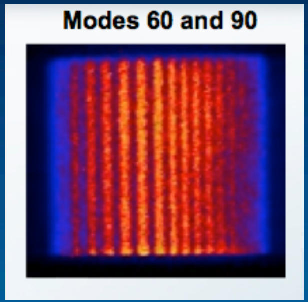
Let's parse the title and derive an outline

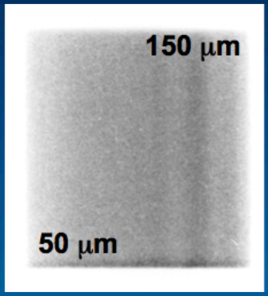
- Hydrodynamic Experiments on the NIF
  - Usefully limits the scope of what I need to cover in 30 minutes
- Accomplishments
  - The work of others (Bruce Remington, Alexis Casner, Vladimir Smalyuk, Carolyn Kuranz, Randy Kanzleiter, Forrest Doss, Ma, ConA team)
- Opportunities
  - One man's opinion

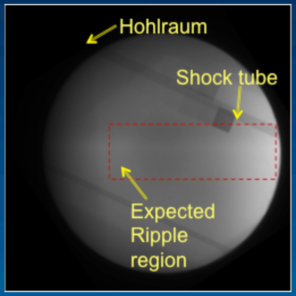
Hydrodynamic experiments at NIF

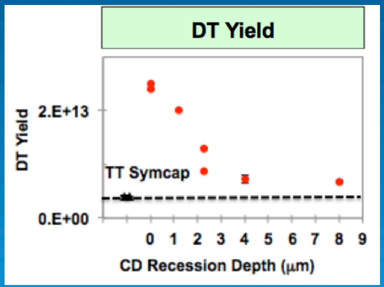
- Compressible Spherical Pistons
  - Convergent Ablators
- Instability growth factor studies
  - Hydro Growth Radiography Platform
  - ART, Rad SNRT
- Interfacial Mix and/or Turbulence
  - CD Mix
  - Shock/Shear

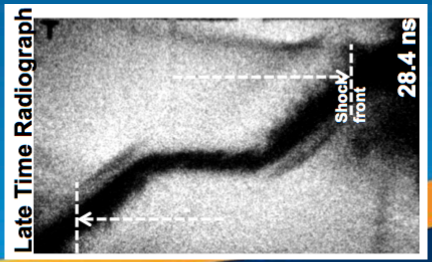




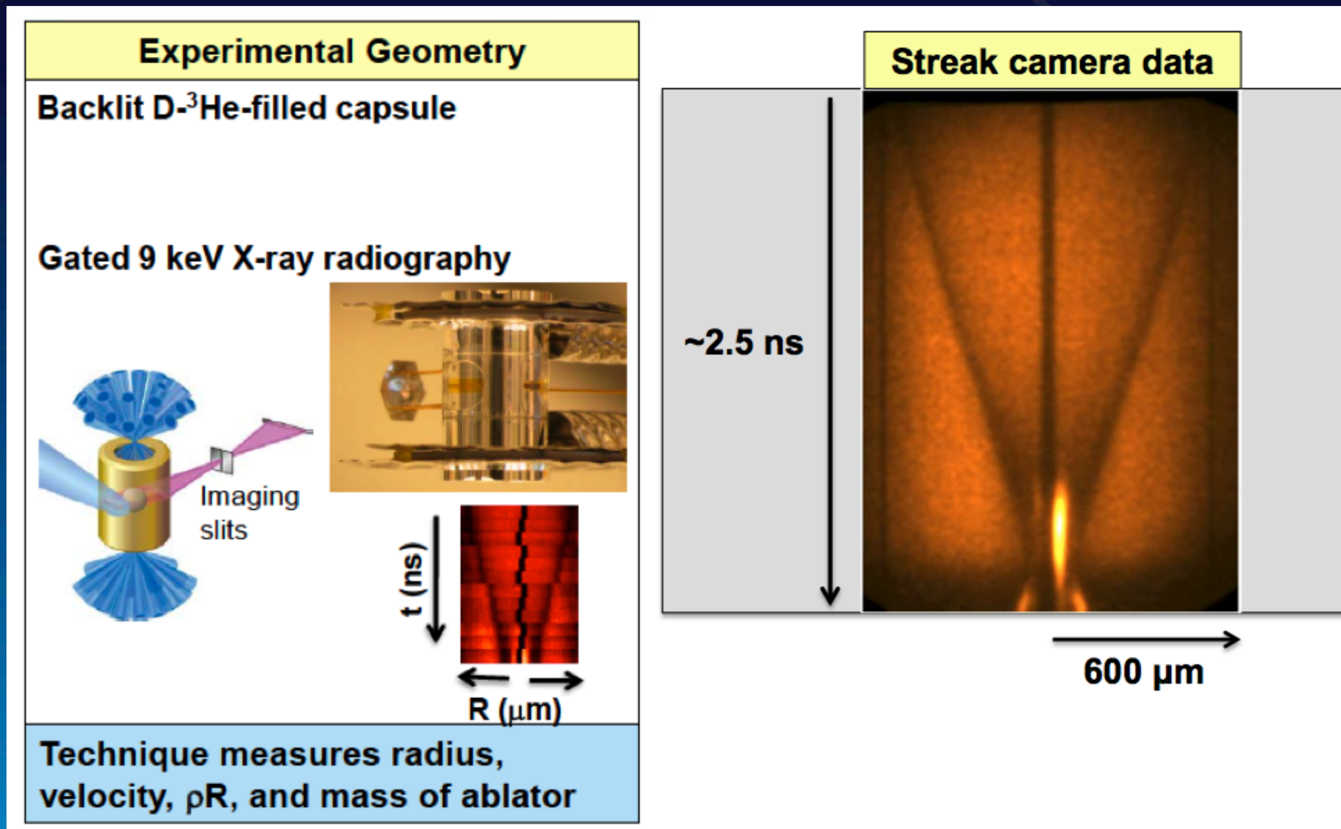








Convergent ablator platform evolved to being an exquisite diagnostic of the behavior of the spherical piston on which all else relies in ICF



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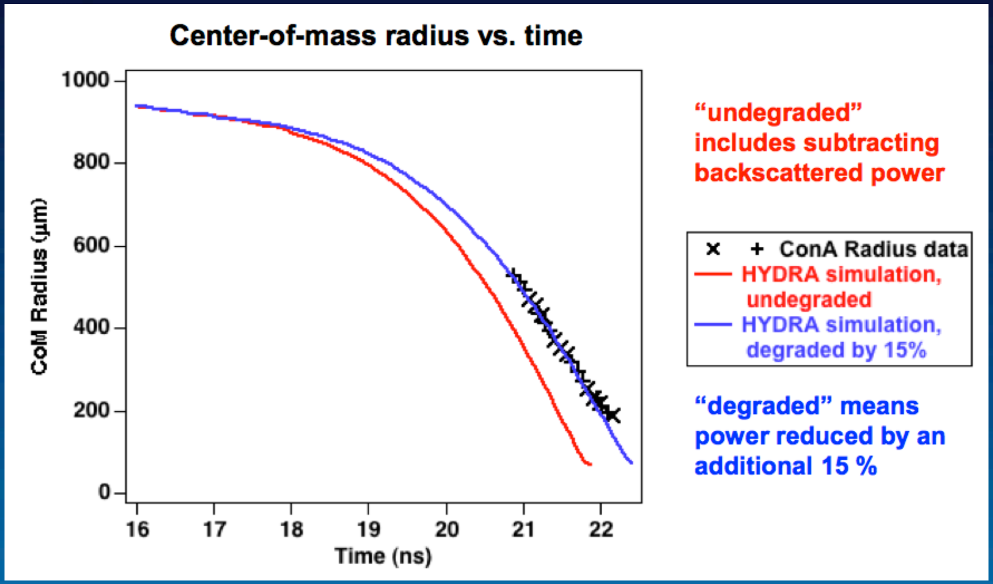
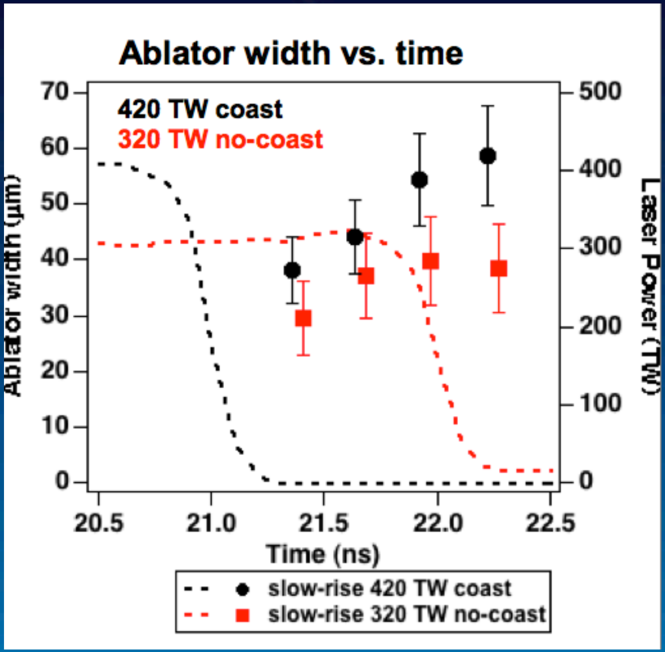
Meezan, et al.

Convergent ablator platform evolved to being an exquisite diagnostic of the behavior of the spherical piston on which all else relies in ICF





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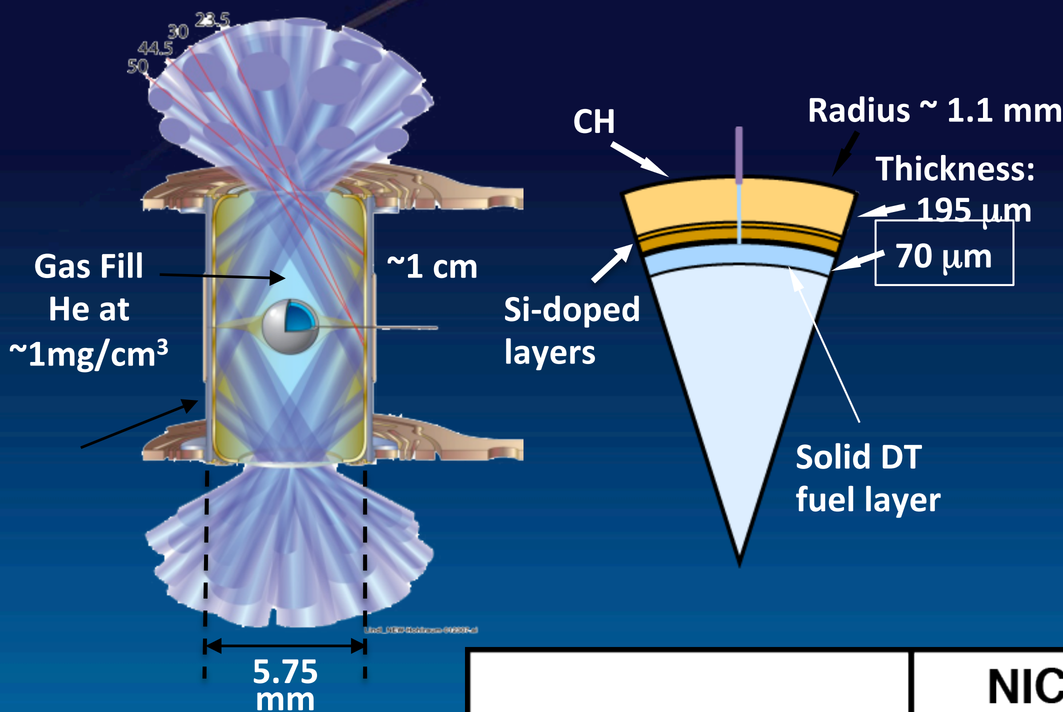
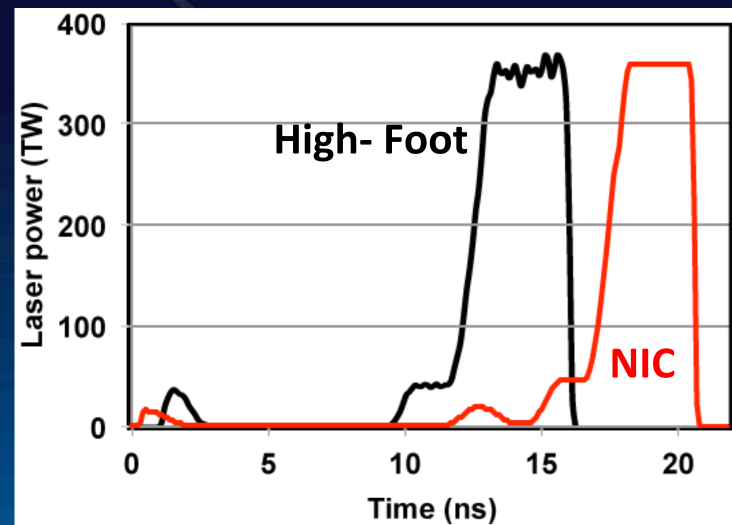
Meezan, et al.

"High-foot" CH design uses same target with shorter laser pulse to reduce growth of surface perturbations





	NIC Low-foot	High-foot
Adiabat	~1.5	Increased to: ~2.5
In-flight aspect ratio, (IFAR)	~20	Reduced to: ~7
Convergence	~45	Reduced to: ~30

If we are in a regime where amplitude = seed * GF then measuring the GF is important

- The high foot campaign trades off high gain potential for stability.
- The Hydro Growth Radiography platform allows us to directly test the underlying hypothesis: high foot => lower GFs.

$$kA^{*}\Delta uf - kv_{a}, \quad early \quad RM$$

$$\sqrt{\frac{kAg}{1+kL_{\rho}}} - kv_{a}, \quad late \quad RT$$

- **Lower growth in Hi-Foot in RM phase because of shorter t_{RM}, higher v_{abl}, and fewer shocks**
- **Lower growth in Hi-Foot in RT phase because of larger L = grad(ρ)/ρ and higher v_{abl}**

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Remington, et al.

If we are in a regime where amplitude = seed * GF then measuring the GF is important

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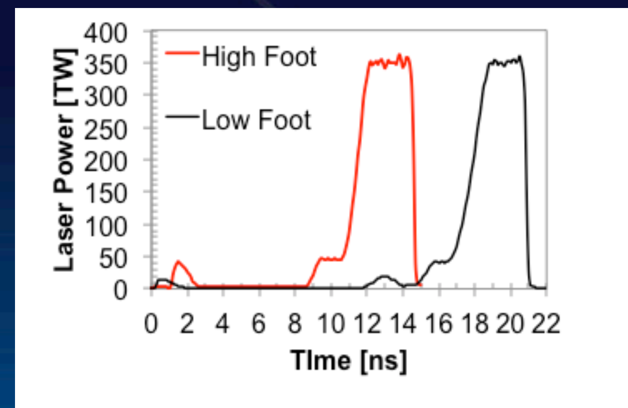
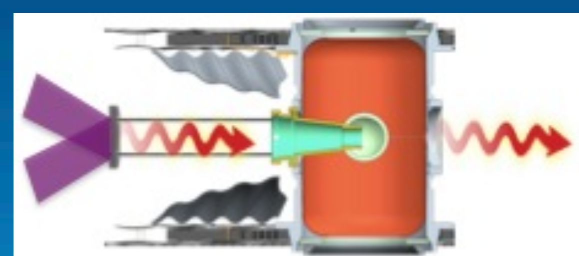
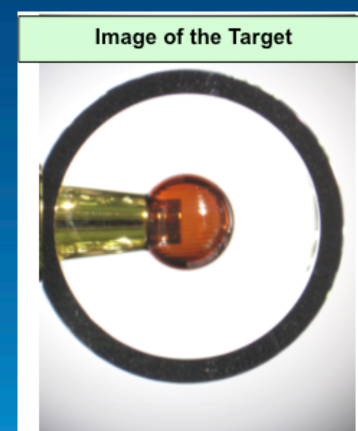






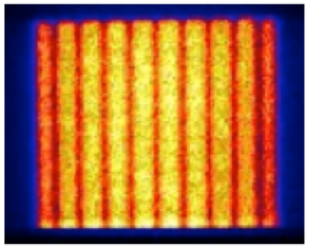
Remington, et al.

If we are in a regime where amplitude = seed * GF then measuring the GF is important

- Though the data requires some time shifting, by using amplitude as a function of wavelength current we can compare these apples and oranges.
- This platform is, in my opinion, a masterpiece of taking advantage of existing tech (slide cone, BL) to quickly answer an important question.

Radiographs with Low-Foot Drive

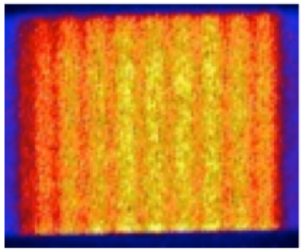
Mode 60



Shot N130602 @ 19.3 ns

Radiographs with High-Foot Drive

Mode 60

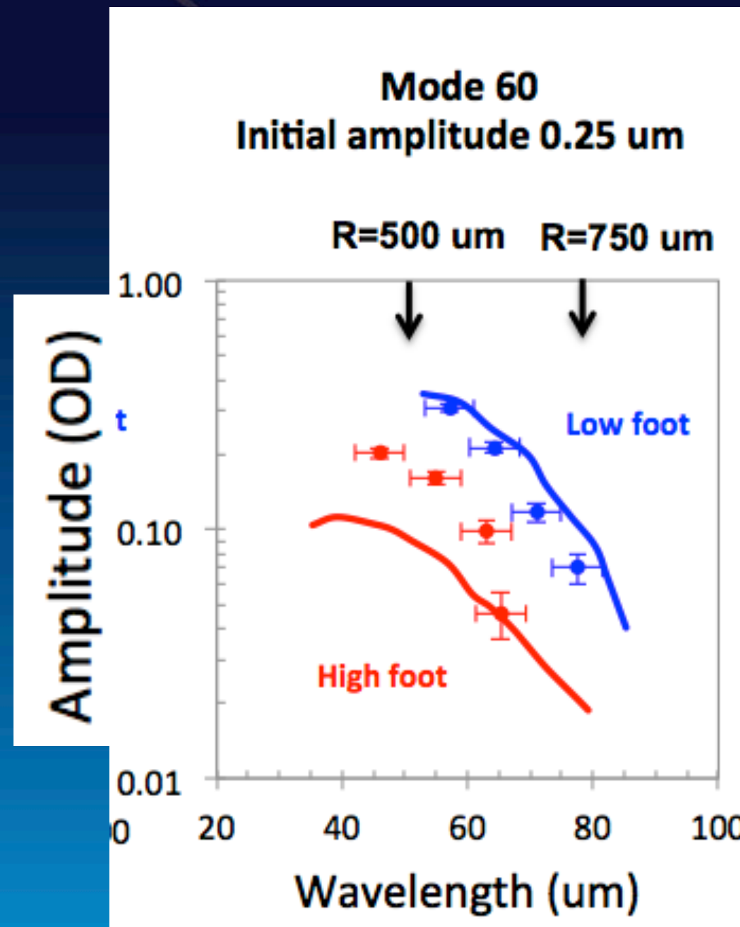


Shot N130702 @ 13.7 ns

Smalyuk, et al.

If we are in a regime where amplitude = seed * GF then measuring the GF is important

- Though the data requires some time shifting, by using amplitude as a function of wavelength we can compare these apples and oranges.
- This platform is, in my opinion, a masterpiece of taking advantage of existing tech (slide cone, BL) to quickly answer an important question.



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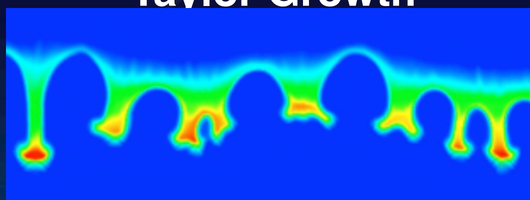
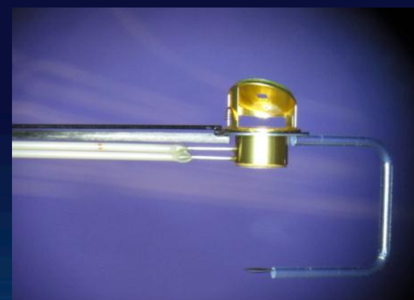
Smalyuk, et al.

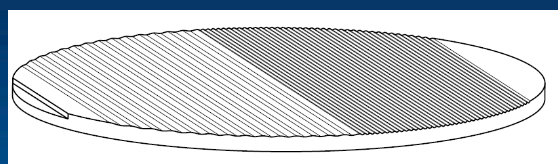
Ablative RT is to study the ablative RTi in the deep nonlinear regime and achieve bubble merger regime.

Highly-nonlinear Rayleigh-Taylor Growth

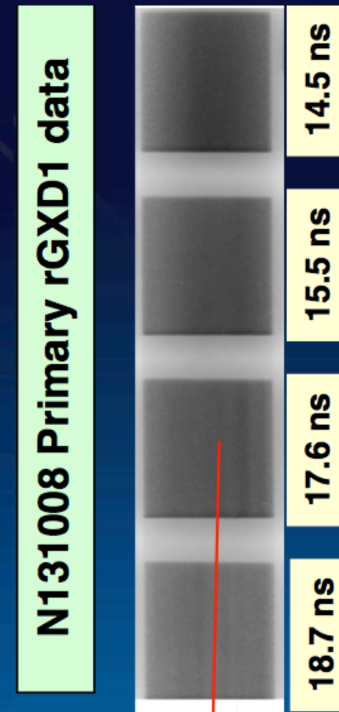




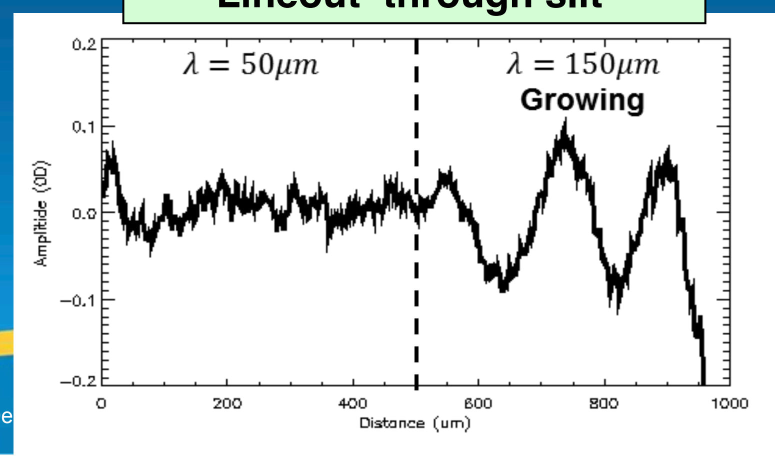
150 μm 50 μm ripples



Driven from this side



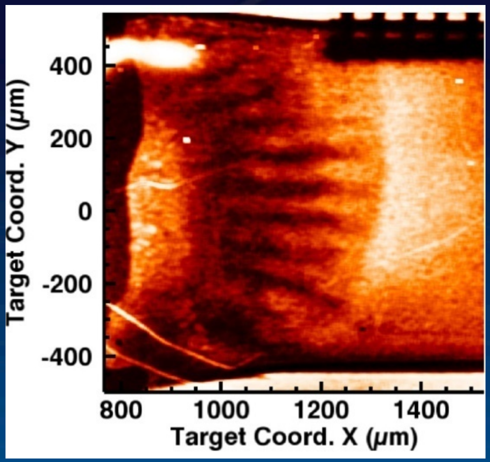
Lineout through slit



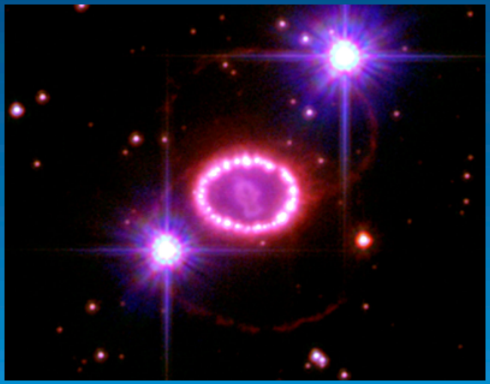
- **Rarefaction wave transferred the modulations from the back surface to front surface.**
- **For the 150mm case the amplitude of the od modulations was significantly greater than postshot simulations.**

NIF will allow the exploration of the combined effects of radiative shocks and instability growth.

Supernova relevant hydrodynamics

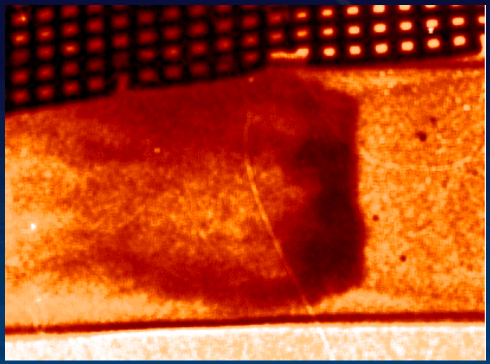


Scaled model of instabilities at H/He interface of SN1987A

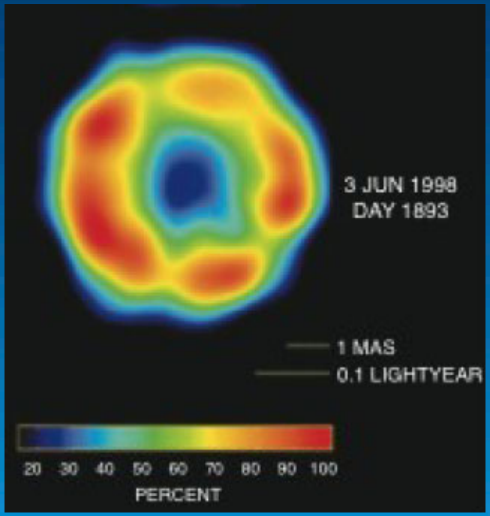


SN1987A, a core-collapse, blue supergiant supernova (HST)

Supernova relevant radiative shocks



20x shock compression by radiative losses



SN1993J, structure may be due to radiative collapse (Bartel, Science, 2000)

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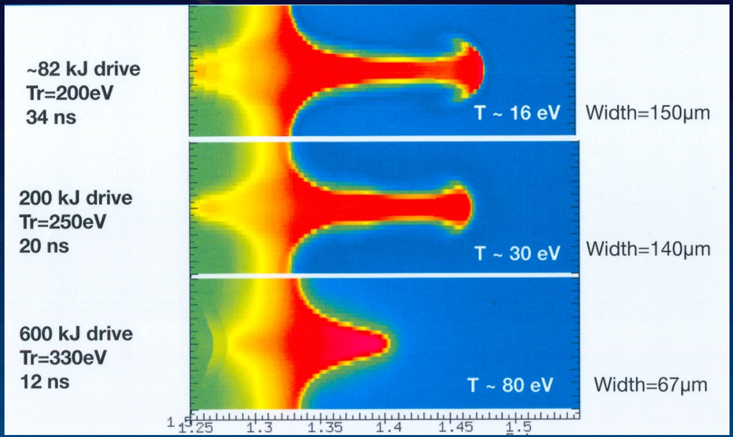
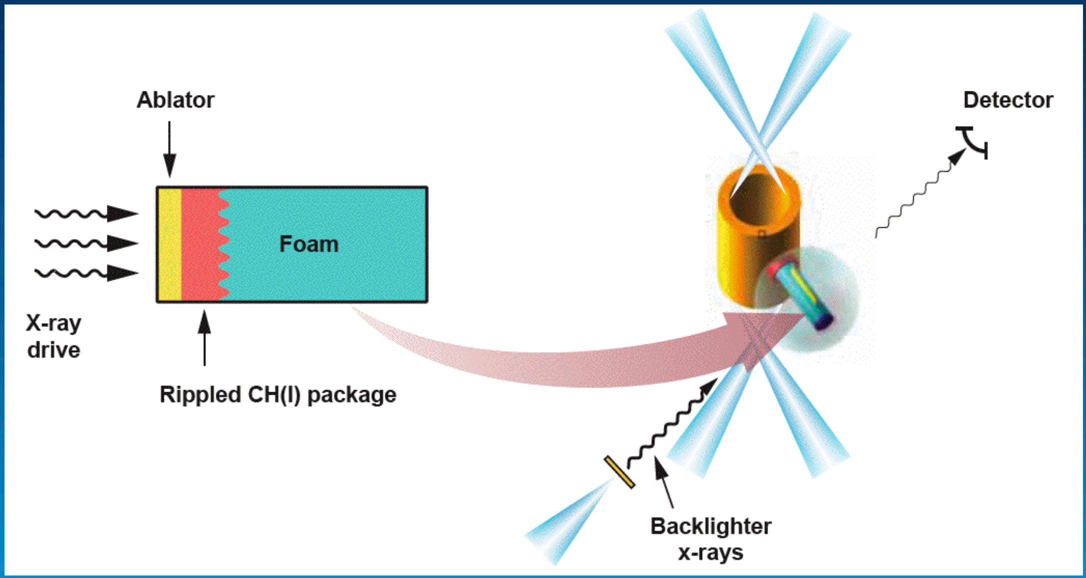
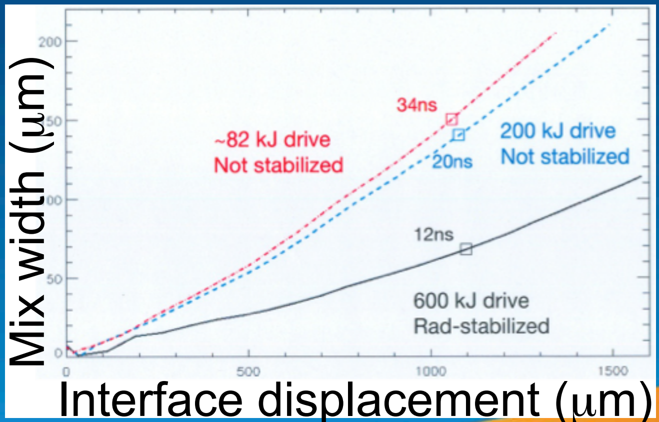
Kuranz, et al.

As radiation becomes important, the qualitative nature of shock waves and instability growth also changes.

- Initial NIF experiments demonstrated a need to reduce background significantly. This work is underway.

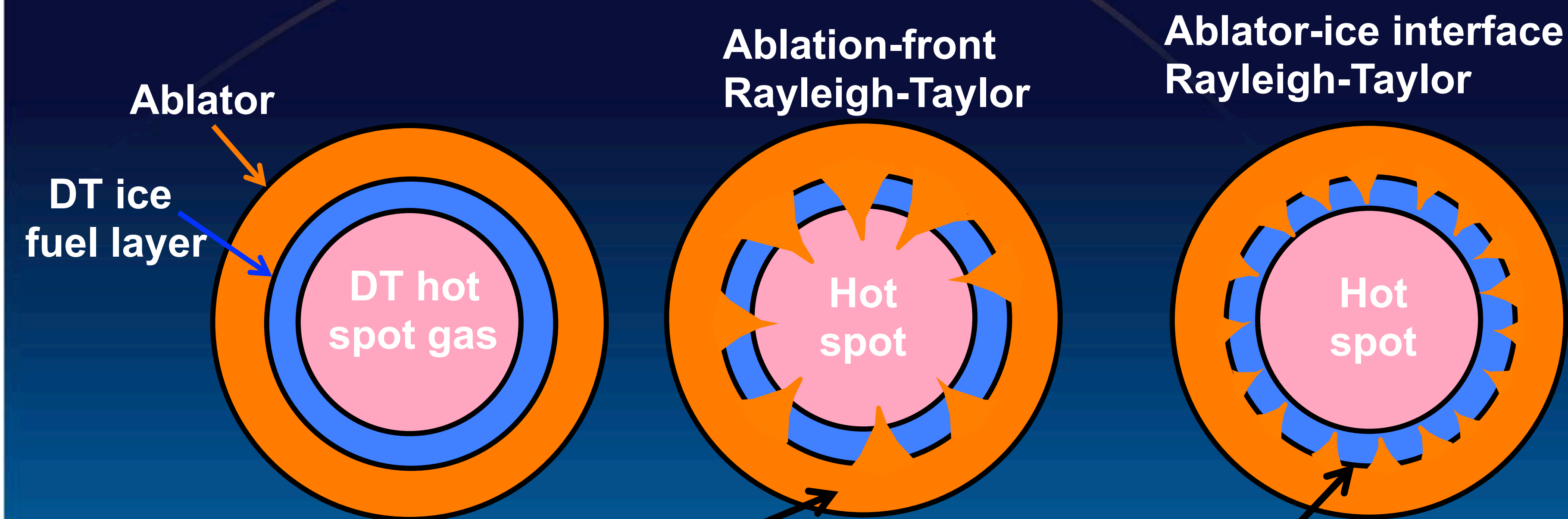






Kuranz, et al.; Miles and Raman

Bruce Remington is leading an international team investigating the physics of mix and ways to mitigate its deleterious effects on ignition.



Strong ablation-front RT growth can contaminate the DT fuel and hot spot, degrading performance

Strong RT growth at the ablator-ice interface can also contaminate the DT fuel and hot spot

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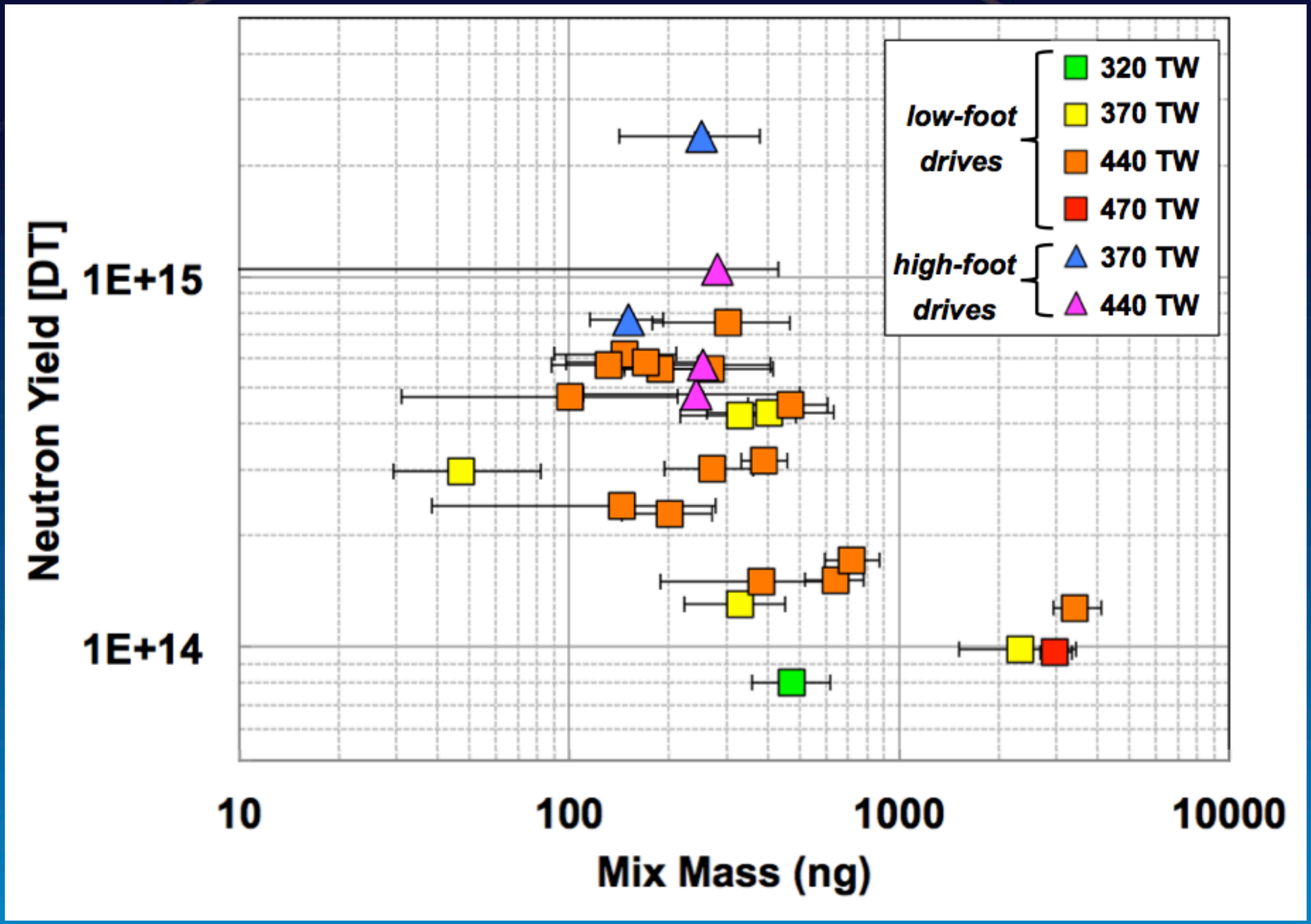
Remington, et al.

Before collecting experimental data, the low foot point design was thought to be robust to ~90ng of mix. If the xray/neutron yield ratio technique is as accurate as it is precise, nature disagreed.



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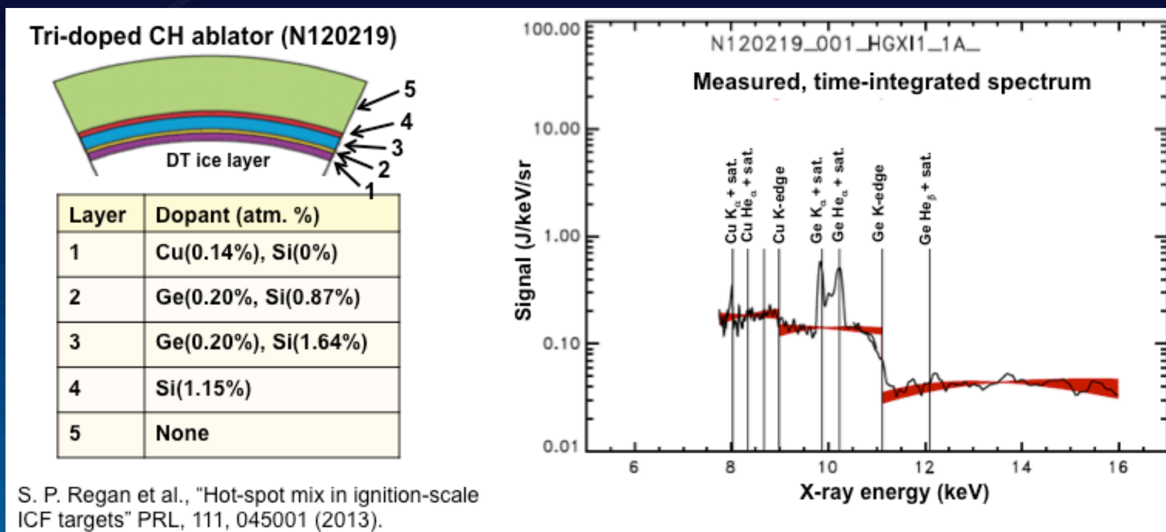
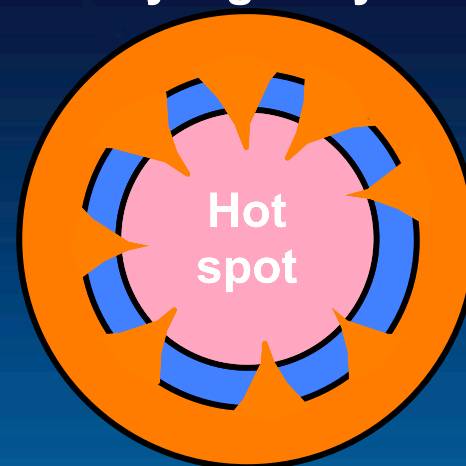
Ma, IFSA, 2013

Strong ablation-front RT growth clearly contributes to mix, unless there is another mechanism to make the initially-distant-from-the-core Ge light up. Interestingly, there is no significant Cu detection from the innermost ablator layer.



Layer	Dopant (atm. %)
1	Cu(0.14%), Si(0%)
2	Ge(0.20%, Si(0.87%)
3	Ge(0.20%), Si(1.64%)
4	Si(1.15%)
5	None

Ablation-front Rayleigh-Taylor

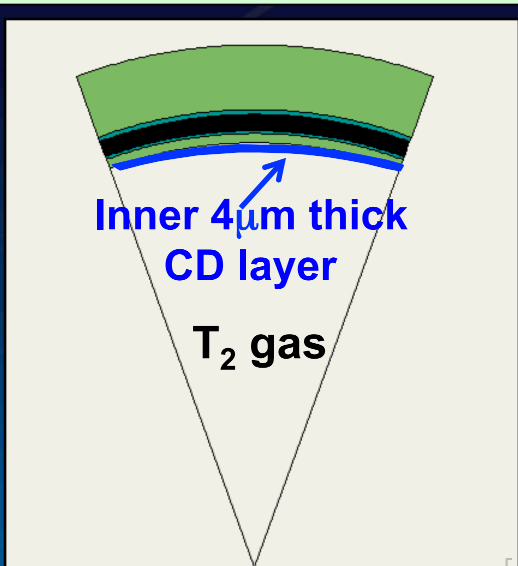


Note that the Cu (in the ablator layer closest to the fuel) didn't light up. Weird.

Regan, PRL, 2013

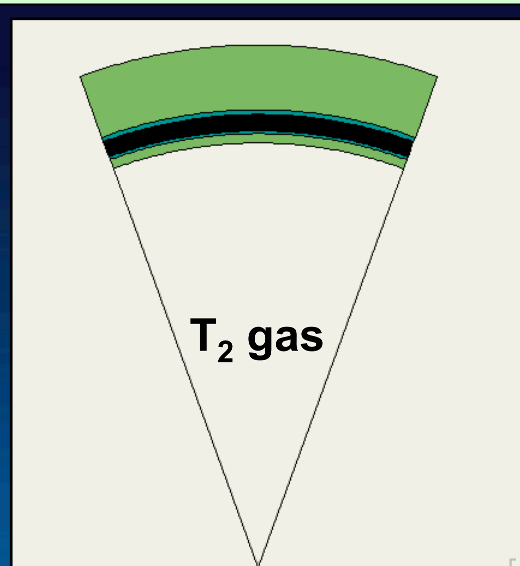
Nil desperandum, fans of ablator/fuel interfacial mix. Warm CD shells filled with (mostly T) show above 'background' DT, indicating for this system the first several microns of the ablator/ice do mix with the fuel 'atomically'.

CH shell with CD layer



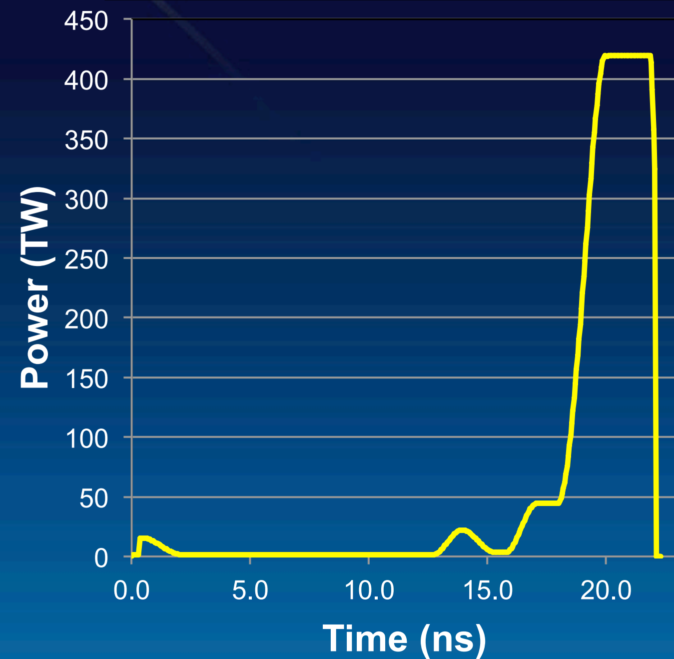
Mix measurement
D + T -> He + n

CH shell



D contamination measurement

Laser Drive 1.5MJ, 435TW

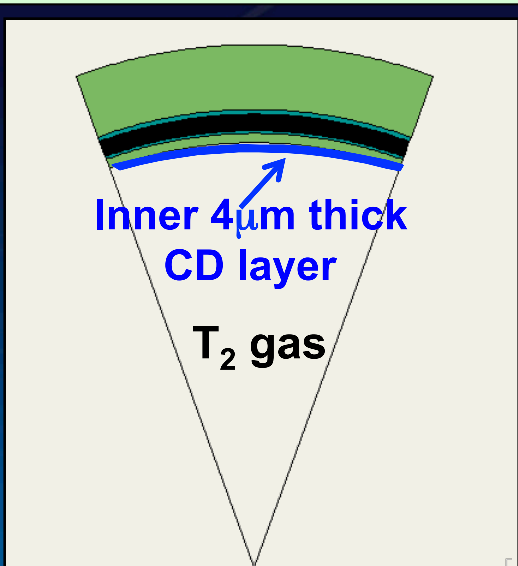


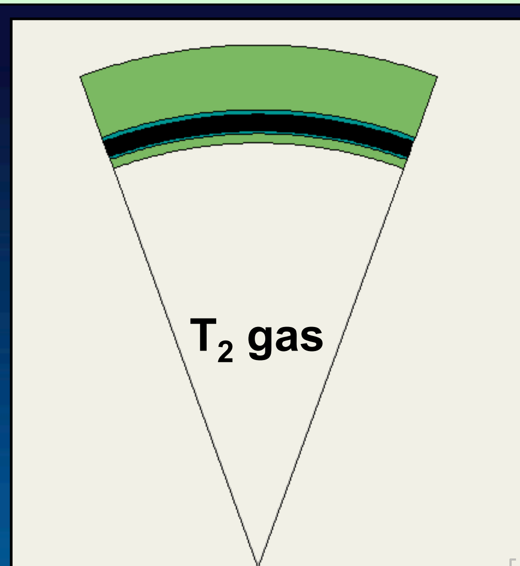
- **CD-Mix experiments measure DT yield due to ablator-gas atomic mix**
- **Shells filled with 11.05 mg/cc T_2 gas at 32K including 0.1% D contamination**

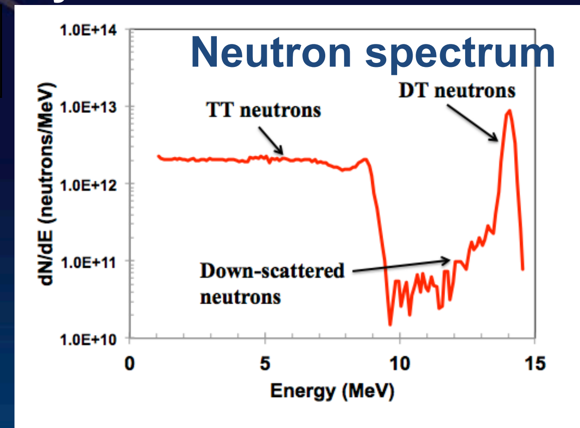
Smalyuk, PRL, 2013

Nil desperandum, fans of ablator/fuel interfacial mix. Warm CD shells filled with (mostly T) show above 'background' DT, indicating for this system the first several microns of the ablator/ice do mix with the fuel 'atomically'.

CH shell with CD layer	CH shell

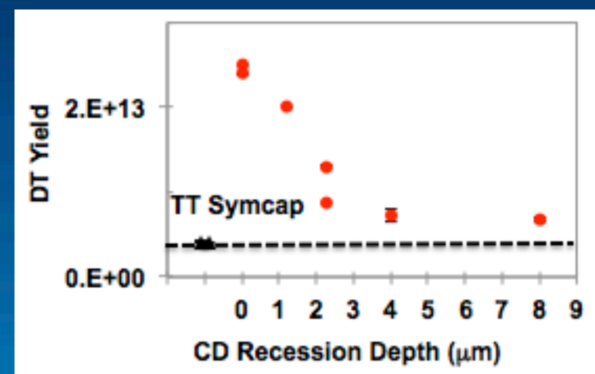


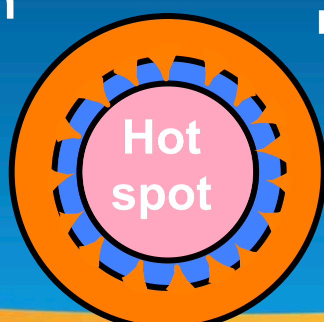




Mix measurement
D + T -> He + n

D contamination measurement





- **CR ~ 20**
- **Surrogacy issues?**

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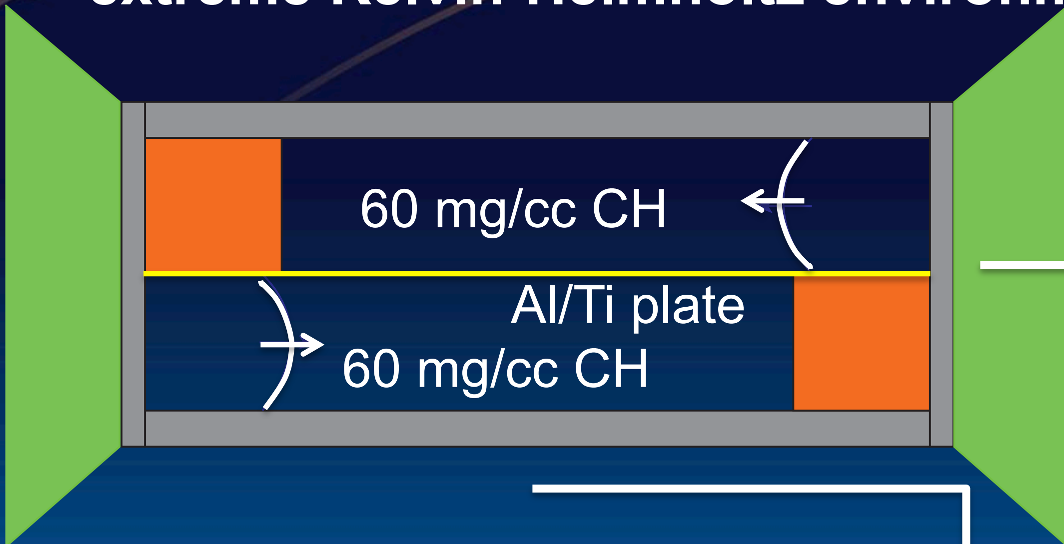
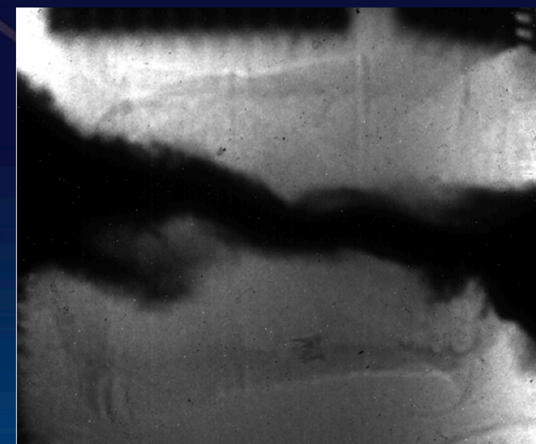
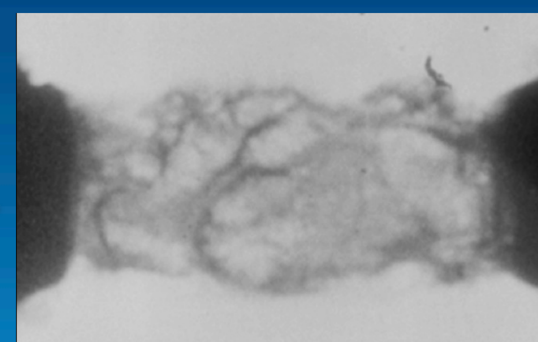
Smalyuk, PRL, 2014

Counterpropagating shear experiment creates extreme Kelvin-Helmholtz environments





- Top right: edge-on view measures tracer mix width.
- Bottom right: transverse view is used to image developing turbulence in the tracer plane.

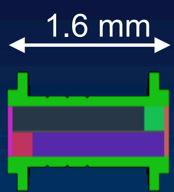


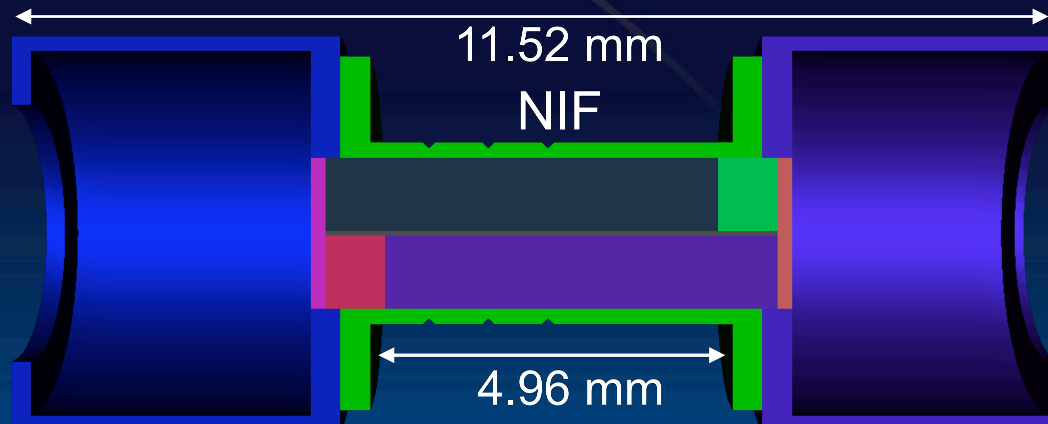
F. W. Doss et al, "Instability, mixing, and transition to turbulence in a laser-driven counterflowing shear experiment," *Phys Plasmas*, **20**, 012707 (2013)

F. Doss, L. Welser-Sherrill, K. A Flippo, E. Loomis, J. Fincke, 2013

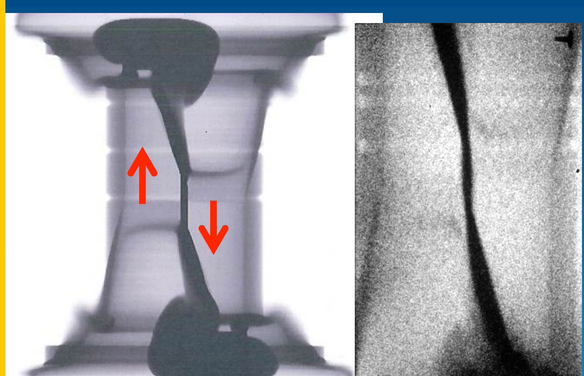
The NIF platform allows connection to the regime explored at Omega.

Omega



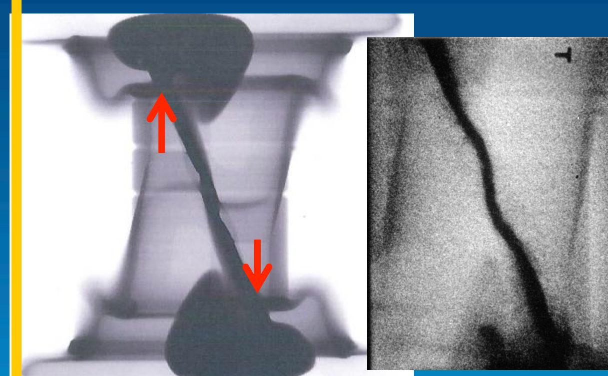


17 ns



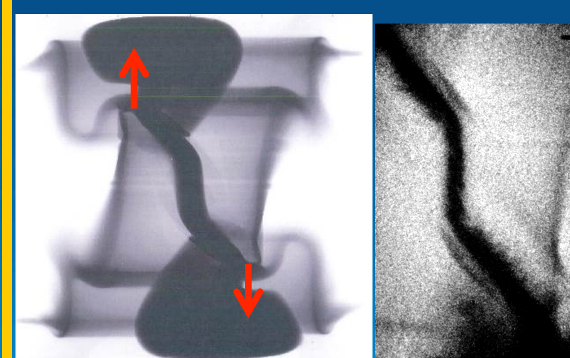
Simulation HGXD Film

22 ns



Simulation HGXD Film

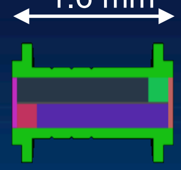
28 ns



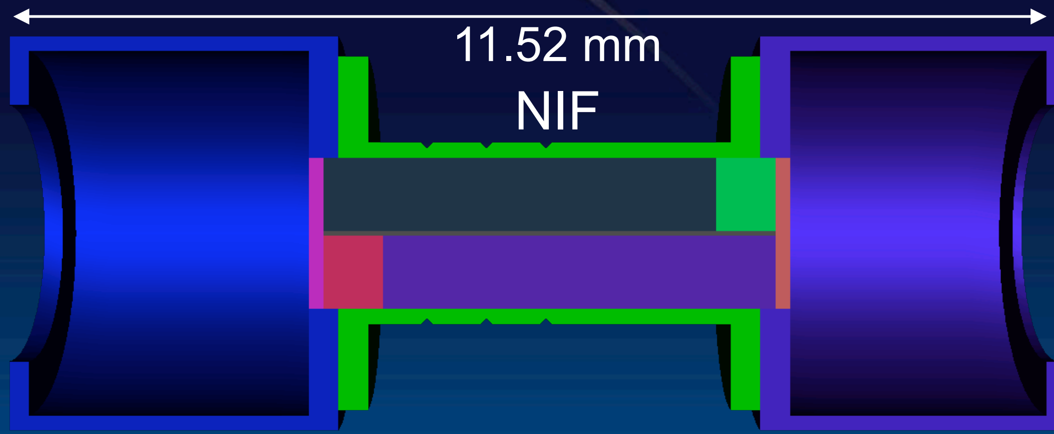
Simulation HGXD Film

shocks

The NIF platform allows connection to the regime explored at Omega.

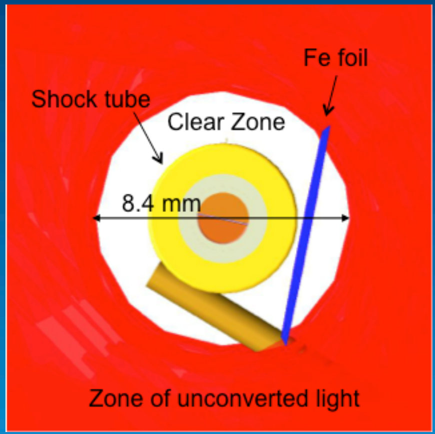


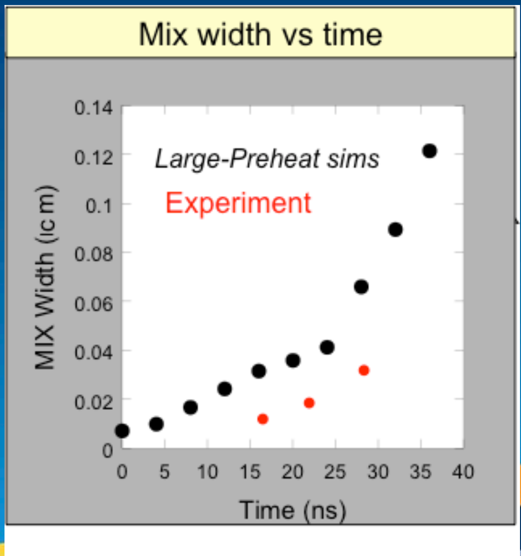
Omega



Developed BABL, which will be of general interest and utility:

- 3mm by 2mm spot
- 6 quads
- 3% conversion efficiency





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Opportunities

- Why does symmetry seem to matter more in experiments than in simulations of the low foot target? Is this ameliorated by increasing the adiabat?

- The velocities we are seeing at 'stagnation' make me question our picture about what is going on in the end game.

- Chunks of material that find themselves in the hot fuel evolve into structures small enough such that T in the fuel can find D in the CD ablator. How does that process go forward? Is BHR 3 the right answer?

Hydrodynamic experiments at NIF

- Compressible Spherical Pistons
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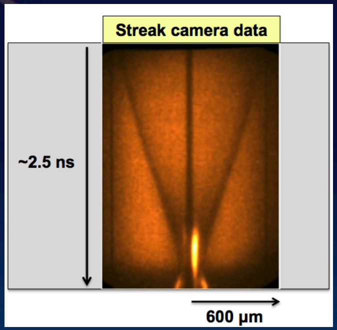

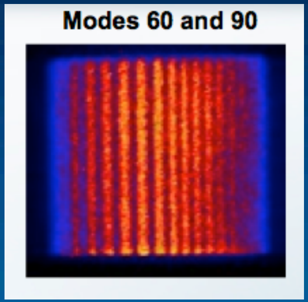

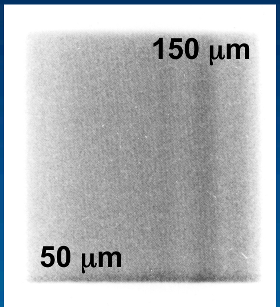

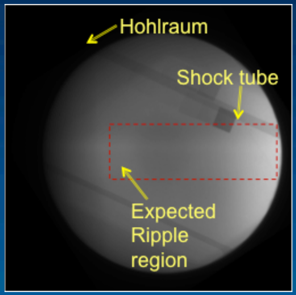

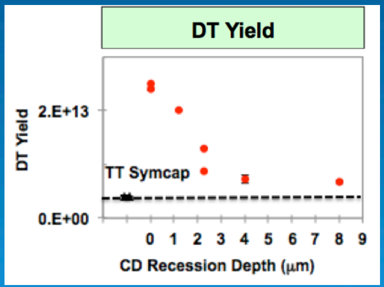

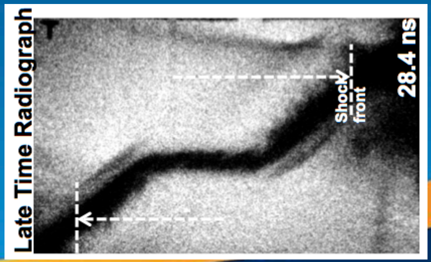

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